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Methyl Bromide as a Delousing Agent[1,2]

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SUMMARY

In January 1942 the Office of the Surgeon General, United States Army, requested the Bureau of Entomology and Plant Quarantine to conduct tests with available fumigants to determine their value as agents for delousing clothing and equipment. After preliminary tests with several fumigants had been made, representatives of the Surgeon General's Office selected methyl bromide as the one best

[1] W. E. Dove and W. G. Bruce assisted in the preliminary tests. A. W. Morrill, Jr., also assisted in certain tests and in the care of insect samples. A. H. Yeomans designed and built the demountable fumigation vault and assisted in designing the individual fumigation bag, both of which are described in a previous publication. (LATTA, R., and YEOMANS, A. H. METHODS AND EQUIPMENT FOR FUMIGATION OF CLOTHING INFESTED WITH BODY LICE. Jour. Econ. Ent. 36: 402-404, illus. 1943.)

[2] Acknowledgments are due to Col. W. E. Stone, Lt. Col. E. C. Cushing, Lt. Col. A. L. Ahnfeldt, and Capt. F. S. Blanton, of the Office of the Surgeon General, and John F. Wolfe, senior architect, Office of the Chief of Engineers, U. S. Army, for suggestions and encouragement, and also to other members of the Office of the Surgeon General, the Office of the Quartermaster General, and the Bureau of Entomology and Plant Quarantine.

[3] Now in the United States Army.

suited for their purpose. Further studies were then made to adapt the method of applying this fumigant to their requirements. The egg stage of the body louse (*Pediculus humanus corporis* Deg.) was used in biological tests, because it was indicated as being the most resistant stage of the insect.

Three methods of application were developed, as follows: (1) Vault fumigation, in which quantities of bagged clothing were exposed to methyl bromide in a demountable gastight vault, (2) individual-bag fumigation, in which one soldier's outfit was exposed in a gastight fumigation bag, and (3) pit fumigation, in which from one to many bags of clothing were fumigated in a pit dug in the ground.

A demountable vault, consisting of plywood panels which could be rapidly bolted together to form a fumigation chamber, was designed and built. Tests made in this unit resulted in recommendations of a dosage of 9 pounds of methyl bromide per 1,000 cubic feet of space (three 1-pound cans per 330-cubic-foot vault) at temperatures above 60° F., or 12 pounds per 1,000 cubic feet (four 1-pound cans per vault) at temperatures below 60°. Damp clothing was successfully fumigated, but the method was not successful with clothing wet enough so that water could be wrung from it by hand.

An individual fumigation bag from 25 to 28 inches wide and 50 inches long, made of material coated with either ethyl cellulose or Neoprene to make it relatively gastight, and fitted with a simple, self-contained closure, was developed. The methyl bromide was contained in a glass ampoule, which was broken inside the sealed fumigation bag. A standard dosage of 20 cc. per bag was selected after dosage-exposure combinations had been compared. All variations in dosage schedules for various temperature levels were then obtained by changing the length of exposure by half-hour steps from three-fourths hour at 55° F. or above, to 2¼ hours at 34° and below. The same exposure to cold alone at —10° and below was equally effective. In the experimental studies the effect of other closures, various coating materials and fabrics, the position of the bag, and the location of the ampoule were tested.

Pit fumigation at dosages comparable to those used in the other methods, was also found to be effective. The best results were obtained with a pit having a small opening and covers made of gastight materials.

It was demonstrated that methyl bromide could be rapidly removed from clothing by aeration. Even without aeration no dermatitis resulted in tests with Army personnel.

Methyl bromide fumigation has been utilized by the armed forces in both the field and at permanent delousing stations at ports of debarkation. Hundreds of thousands of prisoners of war and returning Army personnel have been processed through such stations.

INTRODUCTION

At the time of the entrance of the United States into World War II, louse-borne typhus was a problem of great concern to the

United States Army. Methods of delousing clothing, mainly by steam sterilization, which had been developed during World War I, were considered outmoded, or they required equipment which was too heavy and expensive. Accordingly, in January 1942 the Office of the Surgeon General of the Army requested the Bureau of Entomology and Plant Quarantine to conduct tests with available fumigants to ascertain whether they could be used under military conditions. A fumigant rapid in action, noninjurious to clothing and equipment, effective at low temperatures, not too dangerous to handle, and with no undesirable postfumigation residues or unpleasant odors was desired.

Preliminary studies were made with several fumigants, from which representatives of the Surgeon General's office selected methyl bromide as the one best suited for their purpose. Further studies were then made to develop proper dosage schedules and equipment for adapting this fumigant to the problem. The tests were performed at the Agricultural Research Center, Beltsville, Md.

The trend of the experimental work was determined largely by the concurrent adaptation of the method by the Office of the Surgeon General. The progress was periodically reviewed as each stage of the work was completed, and new problems were attacked in the order of their importance from the standpoint of adaptation of the method.

BIOLOGICAL TECHNIQUE

Early tests showed that the egg of the body louse (*Pediculus humanus corporis* Deg.) was the stage most resistant to fumigants. Therefore, practically all tests were made with eggs. The evaluation of each test was based on whether or not the eggs hatched. At first the eggs, representing all possible ages, were collected from clothing of infested humans. Later, eggs of known age from a colony reared at the Orlando, Fla., laboratory of the Bureau were used. These eggs were shipped by air mail to Beltsville at frequent intervals.

In all tests small pieces of cloth to which the eggs were attached (fig. 1) were inserted at selected locations in the fumigation enclosure. These pieces were aired following treatment and then kept in a moist, warm environment until the eggs hatched. At first samples were incubated in individual shell vials, which were plugged with cotton and kept at a constant temperature of 80° F. and a relative humidity of approximately 50 to 60 percent. Under these conditions hatching was irregular, sometimes extending over a period of 15 days or more. When the temperature was raised to 90° and the relative humidity to near saturation, the eggs hatched in 7 to 10 days and the percentage of hatch was much higher.

A control sample representing each source lot of eggs in each test was incubated along with the treated eggs, as a check on their viability. The results of hatching in the check samples were recorded, but in only one case are they given in the tables of data, because only tests in which eggs hatched, or in which checks indicated the sample to have adequate viability, are presented. The

data on the hatching of controls, given in table 8, are representative of all control samples. Since the records of hatching are expressed in relation to the occurrence or absence of hatching, comparisons between treatments should be made on that basis. Proportionate amounts of hatching are unreliable, because the check samples varied considerably in this respect. In some samples the total number of eggs was estimated, but in most samples the eggs were actually counted.

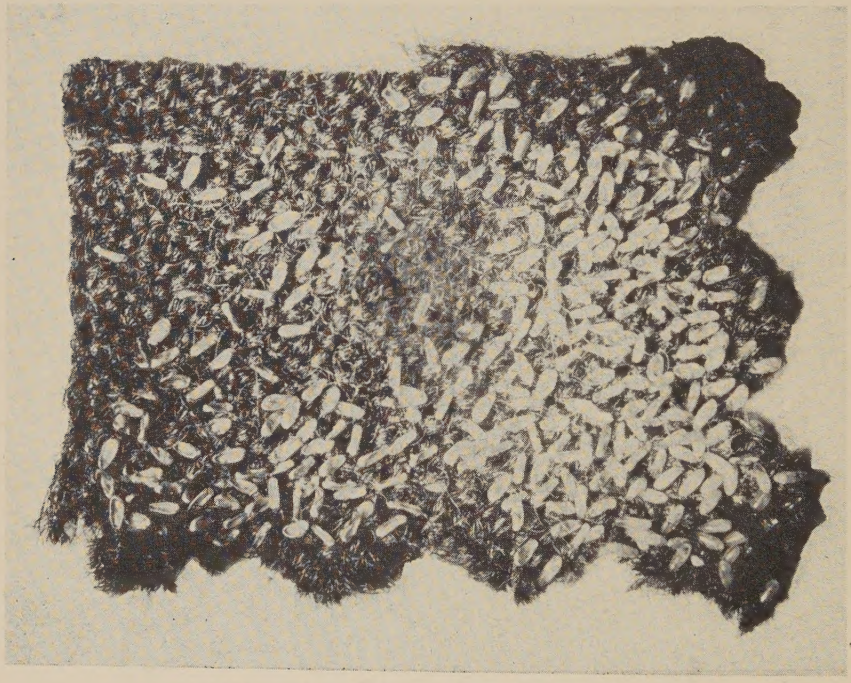

FIGURE 1.—Louse eggs attached to piece of cloth.

PRELIMINARY EXPERIMENTS WITH VARIOUS FUMIGANTS

Seven fumigants were tested in preliminary experiments, as follows: Acrylonitrile, calcium cyanide (dust), chloropicrin, 1,1-dichloro-1-nitroethane (Ethide), ethylene dichloride, methyl bromide, and a mixture of 75 percent of ethylene oxide and 25 percent of ethylene dichloride (Oxyfume).

The tests were made by three methods, as follows: (1) In a water-sealed drum-type fumigator with a capacity of 7½ cubic feet, (2) in a gastight bag with a capacity of approximately 5 cubic feet, and (3) in a metal-lined chamber with a capacity of 107 cubic feet. Not all fumigants were tested under all three methods. All eggs used in these tests were taken from naturally infested clothing.

Drum-Fumigator Method

Chloropicrin, calcium cyanide, and methyl bromide were tested by this method, both with and without a load of clothing in the drum, and with 30-minute exposure of louse eggs. Tests were made in a 55-gallon drum converted into a water-sealed chamber, as described by Johnson,[4] fitted with a small electric fan to circulate the fumigant properly. The results are given in table 1.

Table 1.—*Hatching of louse eggs after 30-minute exposure to chloropicrin, calcium cyanide, and methyl bromide in a drum fumigator (1 test at each dosage unless otherwise indicated)*

NO CLOTHING PRESENT

Fumigant	Temperature (to nearest 5°)	Dosage per 1,000 cubic feet	Eggs exposed	
			Total	Hatched
	° *F.*	*Pounds*	*Number*	*Number*
Chloropicrin	40	14.6	21	1
	50	2.4	27	8
	50	4.8	41	9
	60	2.4	56	21
	60	[1] 4.8	236	36
	60	7.3	146	5
	60	9.7	100	0
	60	[1] 14.6	200	0
	60	29.3	100	0
	70	3.6	100	0
	70	9.7	100	0
	70	[1] 14.6	200	0
	80	4.8	14	0
	80	9.7	31	0
	80	[2] 14.6	149	0
	90	4.8	100	0
	90	9.7	100	0
	90	14.6	100	0
Calcium cyanide	70	4.1	100	0
Methyl bromide	60	4	60	0
	60	6	55	0
	60	8	182	0

CLOTHING PRESENT (load 2 lb. per cubic foot unless otherwise indicated)

Chloropicrin	50	21.9	200	21
	55	14.6	200	28
	60	4.8	200	149
	60	7.3	200	98
	60	9.7	200	200
	60	14.6	200	14
Calcium cyanide	70	[3] 4.1	100	90
Methyl bromide	60	[4] 4	200	55
	60	[4] 5	200	67
	65	[4] 3	200	6
	65	[4] 4	200	4
	65	[3] 4	200	0
	65	[4] 5	200	1
	65	[4] 6	200	0
	70	2	200	60
	70	3	200	29
	70	4	100	1
	70	6	100	0

[1] 2 tests.
[2] 3 tests.
[3] Exposure period 1 hour.
[4] Load 4 lb. per cubic foot.

In tests where eggs were exposed directly to the fumigants with no clothing present, all three fumigants appeared to be effective. When a load of clothing was introduced, however, chloropicrin and

[4] Johnson, A. C. A low-cost water seal fumigator. U. S. Bur. Ent. and Plant Quar. ET-154, 2 pp., illus. 1940. [Processed.]

calcium cyanide were relatively ineffective, and methyl bromide was effective only with dosages of 4 pounds or more per 1,000 cubic feet.

Gastight-Bag Method

About 25 pounds of Army clothing were loosely packed in a gastight bag (described on pages 15–16). Two samples of louse eggs

Table 2.—*Hatching of louse eggs after exposure to various fumigants in a gastight bag filled with clothing (100 eggs exposed, unless otherwise indicated)*

Fumigant	Exposure	Dosage per bag	Temperature	Eggs hatched
	Hours	*Cubic centimeters*	*° F.*	*Number*
Acrylonitrile	2½	5	80	[1] 55
	2½	15	80	[1] 36
	2½	30	80	[2] 0
	2½	60	80	0
	6	15	65	9
	16	10	83–69	0
	17½	15	87–63	0
		Ounces		
Calcium cyanide	2	1	85	[3] 30
	2	2	85	[3] 42
	6	5	65	[1] 0
	16½	1	78–85	[3] 14
	15½	2	77–86	[3] 21
	16	2	83–69	[3] 13
		Cubic centimeters		
Chloropicrin	6	2½	65	0
	6	5	65	[1] 0
	6	10	65	0
	6	10	65	0
	6	25	65	0
	6	50	65	0
	6	100	65	0
1, 1-Dichloro-1-nitroethane	6	10	62	12
	6	25	62	0
	6	100	62	0
Ethylene dichloride	2	8	80	18
	2	32	84	41
	2	100	84	16
	6	200	65	52
	7½	50	60	59
	16	24	85–78	15
	15½	48	86–77	15
	14	100	66–53	24
	15	100	----------	1
Ethylene oxide-ethylene dichloride, 75–25 mixture	6	2	66	67
	6	4	66	35
	6	8	66	11
	6	16	66	3
	6	25	66	3
	6	50	65	0
	6	100	65	0
	6	200	65	1
Methyl bromide	½	5	62	48
	½	10	62	28
	½	15	62	1
	½	16	67	0
	½	21	67	0
	½	25	67	0
	1	16	67	0
	1	21	67	1
	1	25	67	1
	6	1	65	[2] 0
	6	2	65	0
	6	4	65	0
	6	8	65	0

[1] 150 eggs exposed.
[2] 200 eggs exposed.
[3] 50 eggs exposed.

were placed in each bag, one in the center of a folded blanket at the bottom, and one rolled in woolen underwear at the center. The fumigant was poured or otherwise liberated at the top of the bag.

The tests were directed mostly toward medium to long exposure periods (table 2). The temperatures given for overnight exposures are those taken at the beginning and end of each period. Chloropicrin and methyl bromide produced the best results, with acrylonitrile, 1,1-dichloro-1-nitroethane, ethylene oxide-ethylene dichloride mixture following in that order. Calcium cyanide and ethylene dichloride gave poor results.

Use of a Metal-Lined Chamber

In another series of tests chloropicrin and methyl bromide were compared in a metal-lined vault of a type commonly used for other fumigation purposes. Except for one exposure of 1 hour, the periods were limited to 30 minutes. The vault had a capacity of 107 cubic feet. All openings were carefully fitted with sponge-rubber gaskets to make the vault gastight. Circulation was provided by a small fan.

In each test clothing at the rate of 2 to 3 pounds per cubic foot was present in the chamber. The louse-egg samples, numbering from 3 to 10, were scattered throughout the load, some of them being placed in the folds of clothing at the centers of well-filled barracks bags. Circulation was maintained throughout the exposure period.

Methyl bromide at the rate of 6 pounds per 1,000 cubic feet produced complete mortality, but chloropicrin was not effective in any test, even when the exposure period was increased to 1 hour (table 3).

Table 3.—*Hatching of louse eggs after half-hour exposure to two fumigants in a metal-lined chamber*

Fumigant	Dosage per 1,000 cubic feet	Temperature	Load per cubic foot	Eggs exposed	
				Total	Hatched
	Pounds	*° F.*	*Pounds*	*Number*	*Number*
Chloropicrin	4.8	65	2	400	142
	10.9	70	2	300	137
	14.6	39	2	600	384
	14.6	55	3	1,000	435
	14.6	57	2	600	187
	14.6	70	2	300	162
	[1] 14.6	65	2½	400	133
Methyl bromide	4	45	3	800	73
	4	65	3	300	19
	4	70	2	400	3
	5	48	3	800	43
	5	62	3	300	3
	6	50	3	800	3
	6	60	2	400	0
	6	70	2	400	0

[1] Exposure period 1 hour.

Discussion

On the basis of these tests methyl bromide was selected as the best fumigant to use in further experimentation. It was the most effective fumigant tried, did not stain clothing, left no odor, was noninflammable, and apparently did not react with articles, especially those made of plastics, that might be included in a soldier's equipment. It was the only fumigant of the series with a low boiling point, apparently an important feature in the consideration of short exposure periods.

Chloropicrin was highly efficient in 6-hour exposures, but was ineffective in short exposures, even with excessive dosages. Also, enough was retained in the clothing to produce tears in the eyes of the wearer several hours afterwards.

Acrylonitrile was inflammable, and much greater quantities of it were required than of methyl bromide or chloropicrin. In individual fumigation-bag tests 1,1-dichloro-1-nitroethane was effective at approximately the same dosage as acrylonitrile, but it left a lingering odor in clothing. The mixture of ethylene oxide and ethylene dichloride was also inflammable, and even greater dosages of it were required than of the above-named fumigants. Calcium cyanide was ineffective, left an odor in clothing, and often stained garments that were moist or sweaty. Ethylene dichloride was not efficient, even in 6-hour exposures, and was also inflammable.

FURTHER EXPERIMENTS WITH METHYL BROMIDE

After the preliminary tests had been completed, studies were concentrated on the use of methyl bromide. Three methods of application were developed, and exhaustive studies were conducted on each of these to determine dosage schedules suitable under various conditions. These methods were (1) vault fumigation in which quantities of clothing were exposed to methyl bromide in a demountable gastight vault; (2) individual-bag fumigation, in which one soldier's outfit was exposed in a gastight fumigation bag, the fumigant being applied by breaking a glass ampoule containing the exact dosage; and (3) pit fumigation, in which from one to many bags of clothing were fumigated in a pit dug in the ground, the opening being sealed by paper, raincoats, tarpaulins, or other means.

The equipment and biological data for each of these methods will be discussed fully under their respective headings.

Vault Fumigation

The military authorities desired a lightweight, demountable fumigation vault of noncritical materials, of a size convenient for transportation when demounted and best suited for efficient operation. An experimental model 9 by 6 by 4½ feet was designed and constructed for demonstration to military personnel. This model was tentatively approved and experimental studies were conducted in it to establish suitable dosage schedules.

The vault was made of sections bolted together to make the complete chamber (fig. 2). All joints were sealed with a nonhardening

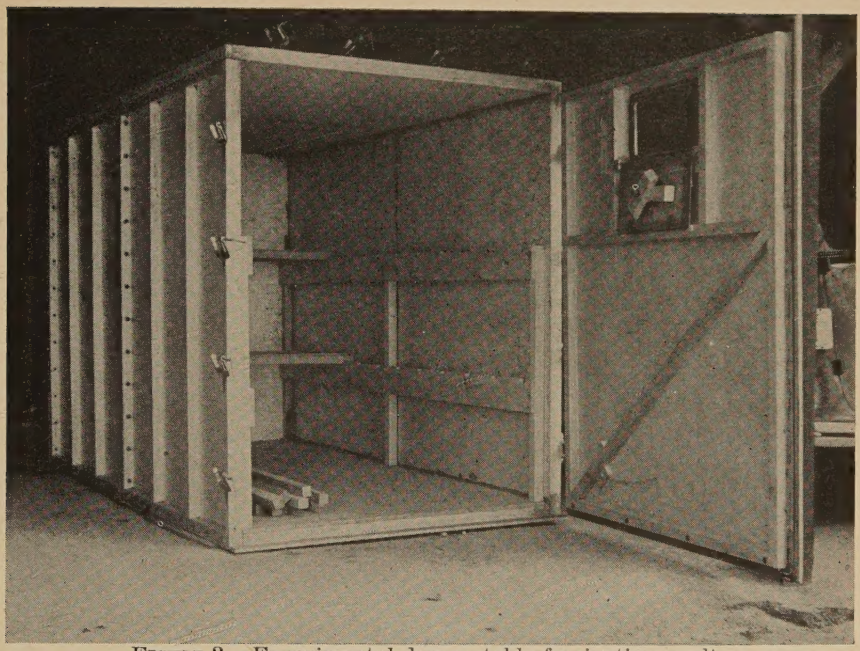

FIGURE 2.—Experimental demountable fumigation vault.

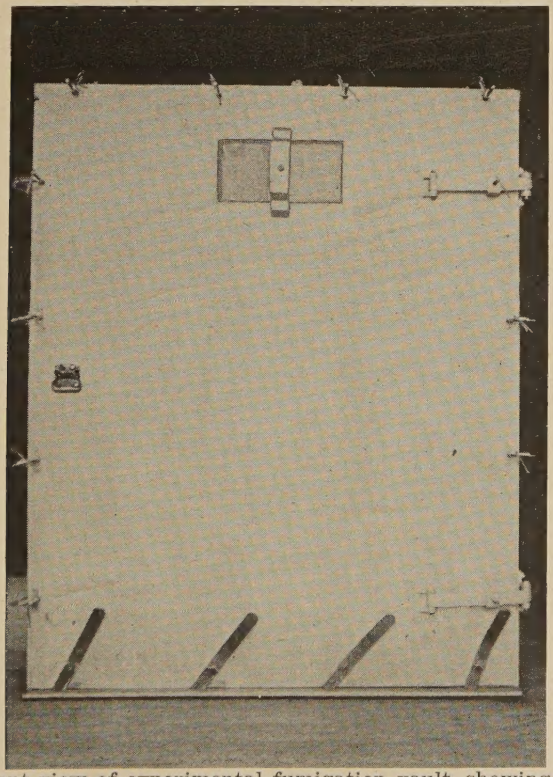

FIGURE 3.—Front view of experimental fumigation vault, showing complete end section used as a door, with air-intake vent in the upper part.

bituminous calking compound to make them gastight. Each section consisted of a single sheet of five-ply, half-inch plywood, reinforced around the edges by a 2- by 2-inch strip. The top, bottom, and side sections consisted of two panels each. The front-end section served as a door (fig. 3) and closed against rubber-strip gaskets. It was fitted with double pin hinges, and a series of clamps around the complete perimeter served to fasten it tightly and evenly against the gaskets. A small intake vent was located in this door panel,

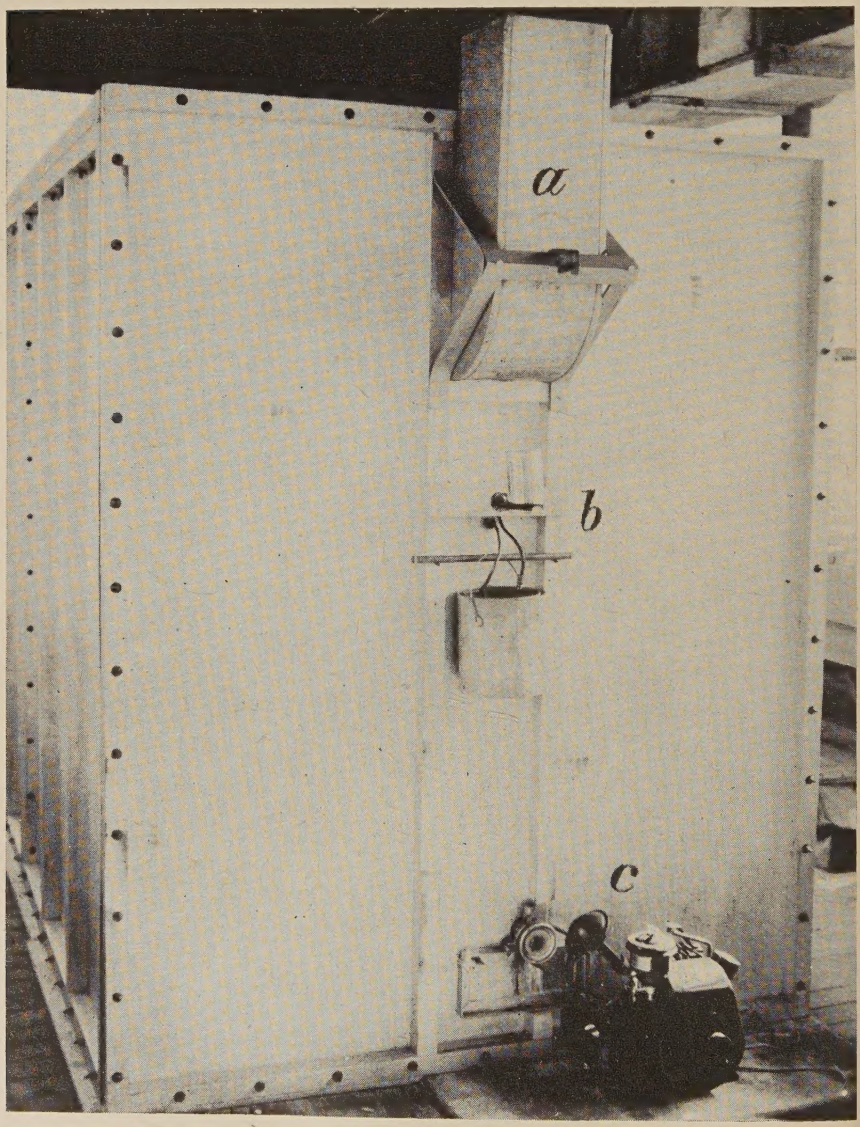

FIGURE 4.—Rear view of experimental fumigation vault, showing (*a*) exhaust vent, (*b*) methyl bromide applicator and volatilizer, and (*c*) gasoline motor used to drive the blower.

to be opened when it was desired to allow fresh air to pass into the vault. The vent door also closed against rubber gaskets. The rear-end section carried all the operational equipment (fig. 4). A multivane blower provided circulation during the fumigation and venting of the fumigant following treatment. It was mounted at floor level (fig. 5) with the outlet directed upward into a short duct on

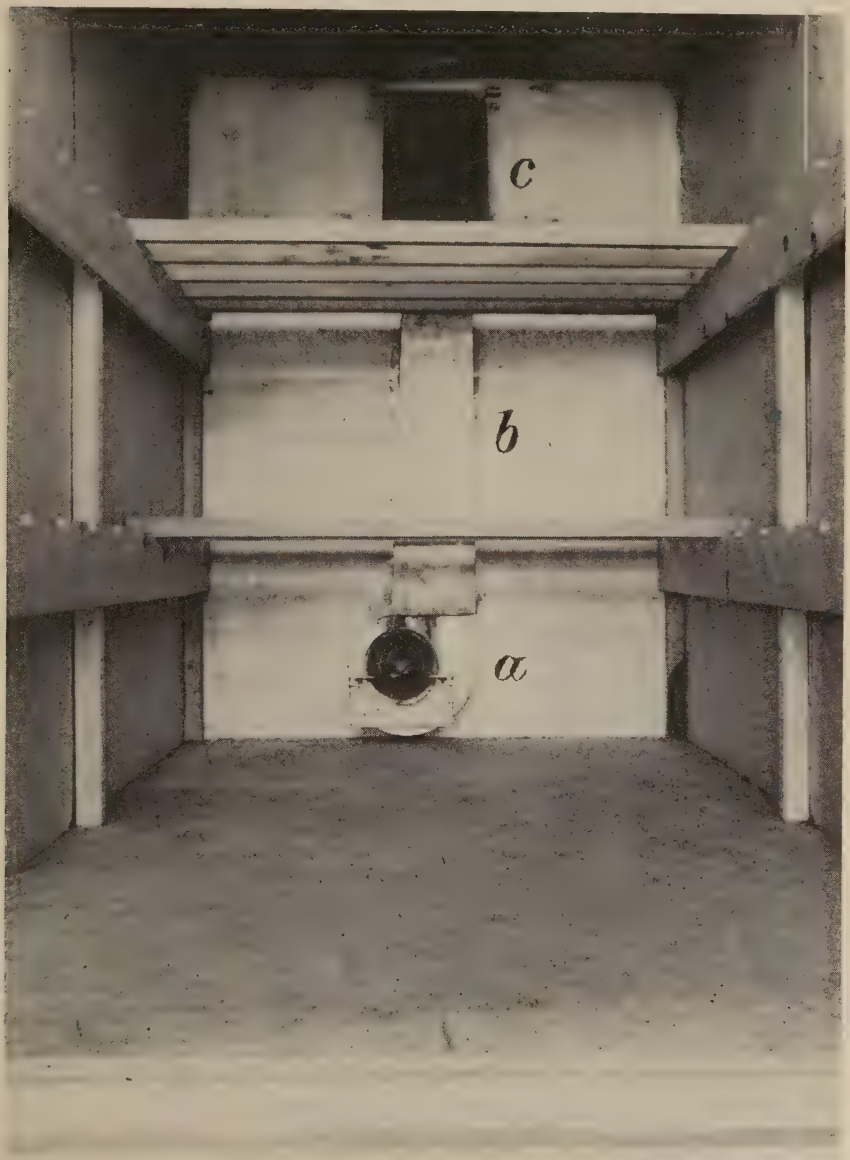

FIGURE 5.—Interior view of experimental fumigation vault, showing location of (*a*) blower, (*b*) circulation duct, and (*c*) exhaust-vent door. The method of shelving is also shown.

the center of the panel. Directly above this duct was located the exhaust-vent opening. The vent door, when closed, was flat against the rear panel and allowed the air stream to pass without interruption. When opened, the lower edge of the vent door protruded completely across the opening of the circulation duct, and served as a baffle to direct the discharge of the blower through the vent into the exhaust duct. Simultaneous opening of the intake vent in the front panel allowed a rapid removal of the fumigant. When closed, the exhaust-vent door was seated against rubber gaskets. It was actuated by a threaded rod, attached to its center and projected through a small opening in the exhaust duct. To close the vent, a wing nut on the threaded rod was tightened. A strap-iron frame around the outside of the exhaust duct received the stress of this operation (fig. 6). Exterior and interior views of the exhaust system are shown in figures 4 and 5.

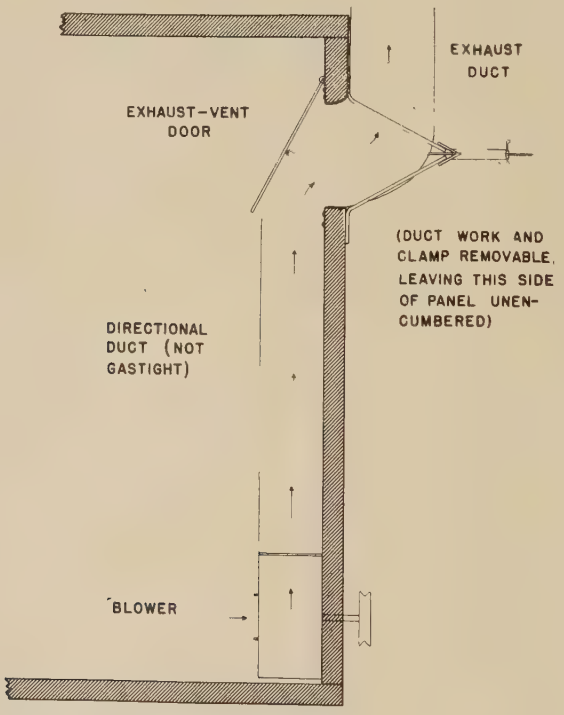
EXHAUST DUCT
EXHAUST-VENT DOOR
(DUCT WORK AND CLAMP REMOVABLE, LEAVING THIS SIDE OF PANEL UNENCUMBERED)
DIRECTIONAL DUCT (NOT GASTIGHT)
BLOWER

FIGURE 6.—Diagram of the exhaust system used on the experimental fumigation vault.

The blower was driven by a gasoline motor (fig. 4, *C*) placed outside the rear panel and operated throughout the exposure period to hasten penetration. The capacity of the blower was large enough to provide for rapid venting, and a 10-minute period was adequate for the removal of all free methyl bromide in the vault. The blower was operated during unloading, which kept a drift of fresh air moving toward the rear and at the same time removed any

additional fumes that were dissipating from the gas absorbed in the clothing. Under these conditions it was not deemed necessary for an operator to use a gas mask, because he would seldom be exposed to appreciable concentrations of methyl bromide for any length of time.[5]

The methyl bromide was applied from 1-pound cans. The cans were punctured by tightening an ingenious clamp arrangement. Before entering the chamber, the fumigant passed through a volatilizer consisting of a coil of copper tubing suspended in a can of hot water.

Removable racks inside the vault were made by placing 2- by 2-inch bars of proper length in notched strips on the side panels (fig. 5).

No arrangement was made for heating the vault or its contents, because it was known that methyl bromide fumigation could be made effective at lower temperatures by increasing either the dosage or the exposure period.

The dismantled vault including the motor weighed 809 pounds. Later models built by the Quartermaster Corps were increased in size to 330 cubic feet, and the top, bottom, and side sections consisted of only one panel each.

The preliminary tests with methyl bromide had indicated that at a temperature of 60° F. or above, and with 30-minute exposures, a dosage of 6 pounds per 1,000 cubic feet was almost completely effective (table 3). Twenty-one tests were made in the experimental vault, with loads of clothing present in each. A dosage of 8 pounds per 1,000 cubic feet was decided upon for these tests, as this rate (two 1-pound cans of methyl bromide in 250 cubic feet) had predetermined the capacity of the vault. One test was made with half this dosage, and in one where wet clothing was involved the dosage was increased to 12 pounds.

Loads of 3 and 5 pounds per cubic foot of space (30 and 50 barracks bags per load) were used. All loads were made up of barracks bags each containing one winter outfit (wool uniform, overcoat, underwear, shirt, shoes, socks, and two blankets) weighing approximately 25 pounds. The preliminary tests had shown that the fumigant would penetrate to the center of loaded barracks bags without undue delay.

In relation to wetness, four types of clothing were used, as follows: (1) Dry clothing, in normal condition. (2) Damp to wet clothing, containing water equal to about 35 to 40 percent of its weight. This was the limit of water that could be contained in the garments without the operator being able to wring out by hand any appreciable amount. This condition was produced by soaking the clothing and allowing it to drain for 2 days, by sprinkling it, or by exposing it to natural rainfall (1½ inches in one instance). (3) Wet clothing, containing water equal to about 50 percent of its weight. This condition was obtained by soaking the clothing and allowing it to drain overnight. (4) Very wet clothing, containing

[5] Methyl bromide, like all fumigants, is injurious to all forms of animal life when inhaled in sufficient quantities. One should observe proper precautions when handling it, to prevent exposure to the fumes. An operator should use an approved gas mask when exposed to the gas at fumigation concentrations. All piping or tubing carrying liquid methyl bromide should be checked frequently to prevent leakage.

water equal to about 65 percent of its weight. This condition was obtained by soaking the clothing and briefly draining it.

The bags of clothing were so placed on the removable racks in the fumigation vault as to leave a space between the layers (fig. 7).

FIGURE 7.—Experimental fumigation vault with barracks bags loaded in three tiers.

Trials were made with the bags divided into two and three tiers, but no differences in results were noted. The temperature of the clothing was noted at the start of each test, and a thermograph record was made of the vault temperature during each exposure.

Samples of viable louse eggs in small cloth bags were placed in folded garments or blankets in the center of selected barracks bags scattered throughout the load, an equal number being on each tier. The samples of louse eggs in damp or wet clothing were wet to about the same condition as the clothing with which they were included. In all except two tests the eggs were from infested clothing obtained in the District of Columbia. Two lots of eggs were from the Orlando, Fla., laboratory. The eggs from infested clothing were of all ages, as shown by the hatching of the check samples. Eggs were segregated so that control and treated samples from one garment or one person could be identified. The hatching larvae were counted and removed daily from each sample. The number of eggs in each sample was estimated, but the number of larvae hatched was an actual count.

The results are given in table 4. With dry clothing no hatching occurred in 9 tests where the temperature was 60° F. or above. In

the tenth test, at 55° F., 1 larva hatched from an estimated 275 eggs. When half-dosage (4 lb. per 1,000 cu. ft.) was used, only about 4 percent of the eggs hatched.

TABLE 4.—*Hatching of louse eggs after half-hour exposure to methyl bromide at 55° F. or above, in a demountable plywood vault loaded with 30 to 50 bags of clothing*

Condition of clothing	Dosage per 1,000 cubic feet	Total samples	Total eggs exposed	Eggs hatched	Fumigation tests	
					Total	Completely effective
	Pounds	*Number*	*Number*	*Number*	*Number*	*Number*
Dry	4	6	500	21	1	0
	8	58	5,820	1	10	9
Damp to wet (35 percent added water)	8	20	878	0	4	4
Wet (50 percent added water)	8	19	635	65	3	0
Very wet (65 percent added water)	8	13	1,010	307	2	0
	12	6	230	48	1	0

In damp to wet clothing complete mortality of louse eggs was obtained in all tests. In wet clothing the results were variable, with hatching in at least one sample in each test. In very wet clothing the treatment was definitely not effective, even in the last test, when the dosage was increased 50 percent (12 lb. per 1,000 cu. ft.).

It was evident from these tests that dry or damp clothing could be fumigated successfully, but that clothing wet enough so that water could be wrung from it by hand should not be fumigated.

On the basis of these experiments a dosage schedule, for vault fumigation, of 8 pounds per 1,000 cubic feet for one-half hour at 60° F. or above, with a load limit of 5 pounds of clothing per cubic foot of space, was recommended to the Surgeon General's Office. A fumigation vault similar to the experimental model was also recommended. In drawing up specifications for procurement of such vaults, United States Army authorities raised the capacity to 330 cubic feet, for better efficiency in operation. Since it was desired to keep the total dosage per vault in an even number of pounds, the dosage was raised to 9 pounds per 1,000 cubic feet.

Later, when the data obtained in the tests represented in figure 12 were nearly completed, recommendations were made for dosage schedules at lower temperatures, proportional to the rate of 9 pounds per 1,000 cubic feet at 60° F. or above, as follows: At 60° and above, use 3 pounds per vault or 9 pounds per 1,000 cubic feet, for one-half hour. Below 60° either use 4 pounds per vault or 12 pounds per 1,000 cubic feet, or add one-half hour of exposure for each 10° below 60°. The mass temperature of the clothing, not that of the air, should be the determining point.

INDIVIDUAL-BAG FUMIGATION

The individual fumigation bag used in the preliminary tests with various fumigants (pages 6–7) was approximately 28 inches wide and 50 inches long, and made of light-weight duck coated with three layers of ethyl cellulose (fig. 8). The exact quantity of fumigant desired was contained in a glass ampoule, which was placed inside the bag as it was being filled with clothing. After the fumi-

gation bag was closed and sealed, the ampoule was broken, releasing the fumigant. This method had worked so well in preliminary tests, and had so many obvious advantages for certain purposes, that extensive studies were undertaken to develop its potentialities further.

FIGURE 8.—Experimental model of the individual fumigation bag, made of duck coated with ethyl cellulose, and closed by the board-clamp method.

The method of fumigation was standard throughout all the tests. An outfit consisting of clothing and blankets, weighing about 25 pounds, was loosely placed in each fumigation bag. Usually two samples of louse eggs were placed in each bag between the folds of a blanket or garment. The bag was then sealed and the ampoule broken. At the end of the desired exposure period the bag was opened, the clothing was shaken out, and the samples of louse eggs were immediately removed.

Prior to fumigation the clothing and blankets were conditioned at the desired temperature and were held at that temperature during the exposure period. Low-temperature studies were made in cold-storage rooms.

The early tests were made with louse eggs obtained from infested clothing, but the later ones with eggs from the Orlando colony. In low-temperature experiments the eggs were given only a brief exposure to the low temperature prior to fumigation, on the assumption that in actual practice the eggs would be at body temperature until clothing was removed for delousing.

The studies were divided into two general groups as follows: (1) Development of the method, including studies on dosage-exposure combinations, type of closure, position of the bag during fumigation, location of the ampoule in the bag, dimensions of the bag, and materials; and (2) development of dosage schedules, including ones for various temperature levels, and the effects of exposure to cold alone.

DEVELOPMENT OF THE METHOD

DOSAGE-EXPOSURE COMBINATIONS

The preliminary tests with methyl bromide had shown effective dosages as low as 1 cc. per bag for a 6-hour exposure, and effective exposures as short as one-half hour with dosages of 16 cc. and above. Further tests were made, therefore, to determine the minimum dosages required for the two exposure periods.

Minimum Dosages at 6-Hour Exposures

A total of 42 tests were made at 3 temperature levels—65°–70°, 36°, and 25° F. The results are given in detail in table 5. At 65°–70° a dosage of 0.75 cc. per bag appeared to be about the minimum, as 3 of 5 tests at this dosage were completely effective and a fourth had only 1 survivor. In 1 test 1 cc. was completely effective, but 0.5 and 0.25 cc. were definitely ineffective. At 36° a dosage of 2 to 3 cc. per bag appeared to be the minimum. In 5 tests with 2 cc. 3 resulted in complete mortality and only 1 louse survived in a fourth. In 5 tests with 3 cc. the results were similar. In 4 tests 4 cc. was completely effective. At 25° a dosage of 4 cc. per bag was effective in 4 out of 5 tests. This was considered to be the minimum dosage, since 2 and 3 cc. gave irregular results, and 5 and 6 cc. were completely effective.

TABLE 5.—*Hatching of louse eggs after 6-hour exposure to methyl bromide in individual fumigation bags*

Temperature	Dosage per bag	Total samples	Total eggs exposed	Eggs hatched	Fumigation tests	
					Total	Completely effective
° F.	*Cubic centimeters*	*Number*	*Number*	*Number*	*Number*	*Number*
25	2	8	579	85	4	2
	3	13	1,089	227	4	1
	4	14	1,039	83	5	4
	5	4	342	0	1	1
	6	4	70	0	2	2
36	2	10	784	12	5	3
	3	14	1,267	45	5	3
	4	10	713	0	4	
65–70	0.25	4	125	22	2	0
	.5	8	490	104	4	0
	.75	10	700	17	5	3
	1.0	2	70	0	1	1

Minimum Dosages at Short Exposures

In tests with short exposures dosages of 12, 15, and 20 cc. per bag were used, which were both above and below the lethal dosages indicated in the preliminary studies. The 12-cc. dosage allowed a slight recovery in 3 of 16 tests with half-hour exposures, in which 8,496 eggs were used. Four tests with a dosage of 15 cc. for half-hour exposures, involving 3,112 eggs, resulted in complete mortality. Seventeen tests with 20-cc. dosages for half-hour exposures, involving 5,419 eggs, were also completely effective, as were 6 additional tests with the same dosage for three-fourths-hour exposures, in which 1,179 eggs were used.

TYPE OF CLOSURE

In the preliminary tests with individual fumigation bags, the bag was closed for fumigation by folding the open end and clamping the fold between two strips of wood held together by C-clamps, as illustrated in figure 8. This closure was not acceptable to military authorities, because it was composed of detachable parts; therefore other types were devised and tested.

Slide fasteners (zippers), slide clamps, and snaps were successively tried and were discarded for one reason or another. The final arrangement was very simple. It consisted of reinforcing the lips of the open end of the bag (fig. 9*A*) with webbed-canvas belting,

FIGURE 9.—A fumigation bag with a fold-over-tie closure: *A*, In open position showing the reinforced but flexible bag opening; *B*, the same bag closed.

which was flexible longitudinally but relatively rigid in cross section. To seal the bag, the mouth was closed and the end of the bag was folded over the reinforcing strip three times and tied in place with conveniently placed tapes (fig. 9*B*). While this closure, known as the fold-over-tie closure, was not so tight as that provided by the board clamp, it was found to be efficient and had obvious advantages from the standpoint of production and utility.

Tests to compare the fold-over-tie type with the board-clamp closure were made at half-hour exposures with dosages of 12, 15, and 20 cc. Four tests with each closure resulted in complete mortality at 12-cc. dosages, as did two tests at 15-cc. and five tests at 20-cc. dosages.

POSITION OF BAG DURING FUMIGATION

The usual procedure was to place samples of louse eggs at two locations within the fumigation bag—at the bottom and at the center. In tests where the ampoule of fumigant was placed at the bottom of the bag, and the bag remained upright during the fumigation, eggs survived in the samples at the center of the bag but not in those at the bottom. This occurred more often in Army type-1 bag (see page 21), which was only 24 inches wide, than in the 28-inch type used in the preliminary experiments. The resulting difference in circumference increased the height of the load of clothing, thus also increasing the height of the sample at the center of the bag. In five tests with a dosage of 20 cc., only one produced complete mortality in the center sample when the Army type-1 bag was left upright during the exposure, as compared with complete mortality in seven tests with the bag lying on its side. It was also noted that dosages as low as 12 cc. were highly effective when the bag was laid on its side.

LOCATION OF THE AMPOULE IN THE BAG

Inasmuch as eggs at the center often survived when the ampoule of fumigant was placed at the bottom of the fumigation bag, the available data were analyzed to determine the influence of the location of the ampoule. In one series of experiments using the Army type-1 bag with a 20-cc. ampoule for half-hour exposures, four of five tests had survivors from samples at the center or top of the bags when the bags remained upright. In seven additional tests with the bag on its side, mortality was complete in samples at the center and at the top.

The effect of placing the ampoule at the center of the bag was then determined. With a 20-cc. ampoule and a three-fourths-hour exposure complete mortality resulted in two tests with the bag upright, but in two of three tests with the ampoule located at the bottom there were survivors.

Following these tests a pocket was placed near the top of each fumigation bag to hold the ampoule (fig. 10). An identifying mark was also placed on the outside of the bag to assist in locating the ampoule (perpendicular white line above the word "Read" in fig. 9).

The removal of the ampoule from its individual cardboard container was found to be unnecessary; in fact, the container helped to retain the broken ampoule and protect the bag from glass cuts.

DIMENSIONS OF THE BAG

As noted previously, when the ampoule was placed at the bottom of the bag mortality was incomplete at the center of the bag or above, in upright bags of narrower dimensions than the original experimental model. It was also shown that if the ampoule was located

at the center or above, or if the bag was laid on its side, complete mortality resulted. From these tests it was concluded that complete mortality could be ensured by such means, and that the dimensions of the bag could be determined solely by convenience.

FIGURE 10.—A fumigation bag opened to show the special pocket in which the methyl bromide ampoule is placed.

MATERIALS

In addition to the original fumigation bag of lightweight duck coated with ethyl cellulose, the Army purchased bags similarly made

except that sateen was used instead of the duck. Later a material coated with Neoprene, a synthetic rubber, was used, two layers of sheeting being sealed together and coated on each outer surface with the rubber. Several other coated materials were tested at various times, as well as some paper products. Data on all these are assembled in this section. The materials are described as follows: [6]

(1) A single layer of duck with three coats of ethyl cellulose (laboratory experimental bag).
(2) A single layer of sateen with three coats of ethyl cellulose (Army type-1 bag).
(3) A double layer of sheeting with three layers of Neoprene, one between and one on each outer surface (Army type-2 bag).
(4) Two layers of waterproof paper with an interlining of tar.
(5) Heavy wrapping paper.
(6) A single layer of cloth coated with vinyl resin.
(7) A double layer of cloth coated with vinyl resin.
(8) Neoprene balloon cloth, coated on one side with aluminum, weight 2.05 ounces per square yard.
(9) A double layer of cloth coated with polyvinyl butyl.
(10) A single layer of cloth coated with resin.
(11) A double layer of sheeting coated with Neoprene, similar to (3) above
(12) A single layer of cloth coated with Vinylite.
(13) Balloon ballinett, a double layer of cloth coated with Neoprene, unaluminized, 8 ounces per square yard.
(14) Balloon ballinett, a double layer of cloth coated with Neoprene, aluminized.
(15) Laminated paper with cloth back.
(16) Paper laminated to cloth.
(17) A double layer of sheeting, with a middle coat between the sheeting of buna S, and outer coatings of Neoprene.
(18) A double layer of sheeting, with three coats of butyl rubber.
(19) A double layer of sheeting with a middle coat between the sheeting of butyl rubber, and outer coatings of Neoprene.

A number of tests were made in which bags of the various materials were compared with bags made of materials 1, 2, and 3. In several instances a sublethal dosage was deliberately used, so that finer comparisons could be made. The results showed that most of the materials were practically as efficient as those coated with ethyl cellulose or Neoprene. A single layer of cloth coated with vinyl resin was probably slightly inferior, and would require an increased dosage. The results of these tests are given in table 6.

DEVELOPMENT OF DOSAGE SCHEDULE

It was already known, when these investigations were begun, that methyl bromide is effective in direct relation to the temperature, and that larger dosages or longer exposures are necessary at the lower temperature levels. Since it was manifestly impractical to have ampoules of various sizes, the variations in dosage schedules were obtained by using different exposure periods.

This method of fumigation was adopted by the Army, and procurement of bags and ampoules was initiated concurrently with the experimental studies. On the basis of preliminary information, a 20-cc. ampoule was selected as the most satisfactory; therefore this dosage was used in all tests. Bags coated with either ethyl cellulose or Neoprene were used in all experiments. The louse eggs were from the Orlando colony, unless otherwise noted.

[6] The descriptions of the materials are incomplete in some instances, but they represent the best information available.

TABLE 6.—*Comparison of bags of various materials with the experimental, or Army-type bags (dosage, 20 cc. per bag unless otherwise indicated)*

Bag material	Temperature	Exposure	Eggs exposed		Fumigation tests	
			Total	Hatched	Total	Completely effective
	° F.	Hours	Number	Number	Number	Number
(4) Laminated paper	70	6	[1] 245	0	2	2
(5) Heavy wrapping paper	70	6	[1] 195	111	2	0
(1) Experimental	70	6	[1] 350	0	2	2
(6) Vinyl resin, single	0	2¼	1,279	0	2	2
(2) Army-type 1	0	2¼	661	2	1	0
(3) Army-type 2	0	2¼	592	0	1	1
(6) Vinyl resin, single	0	2¼	784	0	2	2
(3) Army-type 2	0	2¼	414	0	1	1
(6) Vinyl resin, single	25	1¾	1,205	2	2	1
(3) Army-type 2	25	1¾	571	4	1	0
(6) Vinyl resin, single	32	1½	1,592	14	2	1
(3) Army-type 2	32	1½	1,218	0	2	2
(6) Vinyl resin, single	46	¾	1,131	0	2	2
(3) Army-type 2	46	¾	409	0	1	1
(6) Vinyl resin, single	48	½	823	13	2	1
(3) Army-type 2	48	½	381	0	1	1
(6) Vinyl resin, single	68	½	1,243	143	2	1
(3) Army-type 2	68	½	464	0	1	1
(6) Vinyl resin, single	68	½	2,044	0	3	3
(7) Vinyl resin, double	68	½	768	0	1	1
(3) Army-type 2	68	½	743	0	1	1
(8) Balloon cloth	70	½	394	12	1	0
(9) Polyvinyl butyl	70	½	307	10	1	0
(10) Resin-coated	70	½	265	9	1	0
(11) Neoprene	70	½	156	0	1	1
(3) Army-type 2	70	½	182	0	1	1
(12) Vinylite	52	½	360	16	1	0
(13) Ballinett	52	½	400	0	1	1
(3) Army-type 2	52	½	900	0	2	2
(13) Ballinett	40	½	211	0	1	1
(3) Army-type 2	40	½	285	0	1	1
(13) Ballinett	60	½	491	3	1	0
(3) Army-type 2	60	½	460	66	1	0
(13) Ballinett	68	¾	671	1	1	0
(3) Army-type 2	68	¾	677	1	1	0
(13) Ballinett	65	¾	200	0	1	1
(14) Ballinett	65	¾	400	0	2	2
(15) Laminated paper	65	¾	200	0	1	1
(16) Paper-cloth	65	¾	200	0	1	1
(3) Army-type 2	65	¾	200	0	1	1
(17) Neoprene-buna S	38	1½	1,140	0	1	1
(2) Army-type 1	38	1½	1,078	0	1	1
(3) Army-type 2	38	1½	1,055	0	1	1
(17) Neoprene-buna S	40	1¼	555	0	1	1
(2) Army-type 1	40	1¼	845	0	1	1
(3) Army-type 2	40	1¼	673	0	1	1
(17) Neoprene-buna S	60	½	685	1	1	0
(2) Army-type 1	60	½	565	79	1	0
(3) Army-type 2	60	½	860	3	1	0
17) Neoprene-buna S	70	½	715	0	1	1
(2) Army-type 1	70	½	340	0	1	1
(3) Army-type 2	70	½	560	0	1	1

[1] Dosage 0.75 cc. per bag.

TABLE 6.—*Comparison of bags of various materials with the experimental, or Army-type bags (dosage, 20 cc. per bag unless otherwise indicated)*—Continued

Bag material	Temperature	Exposure	Eggs exposed		Fumigation tests	
			Total	Hatched	Total	Completely effective
	° F.	*Hours*	*Number*	*Number*	*Number*	*Number*
(18) Butyl	50	1	560	1	1	0
(2) Army-type 1	50	1	500	2	1	0
(3) Army-type 2	50	1	325	3	1	0
(18) Butyl	55	¼	575	0	1	1
(19) Neoprene-butyl	55	¼	875	2	1	0
(3) Army-type 2	55	¼	1,400	2	1	0

It was also evident that at some temperatures exposure to cold alone would cause mortality of all stages of lice. The experiments were therefore divided into two groups as follows: (1) To determine adequate exposure periods to use in fumigation at various temperature levels, and (2) to determine the effect of exposure to cold alone.

EXPOSURE PERIODS NECESSARY AT VARIOUS TEMPERATURE LEVELS

Louse eggs were fumigated in individual bags with a normal load of 25 pounds of wool clothing and blankets, at temperatures ranging from 0° to 75° F. A total of 438 samples, containing 71,624 eggs, were treated, and approximately 25,000 eggs were observed as control samples. In tests at low temperatures the control samples were divided, one half being exposed to the same temperature as the treated lot for a similar period, and the other half remaining at room temperature. The results are given in table 7.

When the data were plotted (fig. 11), the increase in the exposure necessary was not a straight-line relationship, but tended to level out below the freezing point. A 30-minute exposure was apparently sufficient at 45° F. and above, but at 36° an exposure of 1¾ hours showed survivors in 3 of 4 tests, although 4 tests with 1½-hour and 5 of 6 tests with 1-hour exposures resulted in complete mortality. The survivors at the 1¾-hour exposures were very few. At 25° there were also a few recoveries in 3 of 8 tests at 1¾-hour exposures. At 10° mortality was complete at all exposures of 1 hour or more. At 0° slight survival occurred in 2 of 7 tests at 2¼-hour exposures. Active lice were included in several tests to verify earlier determinations that they were more easily killed than eggs. With one exception, they were readily killed with exposures for ¾ hour at 50° and above, for 1¼ hours at 41°, for 1¾ hours at 36° and 25°, and for 2¼ hours at 0°.

EFFECT OF EXPOSURE TO COLD ALONE

Samples of louse eggs were exposed at various temperatures ranging from −15° to 42° F. The eggs were little affected until they were exposed to temperatures below 0°. At 36° complete mortality of eggs resulted after exposure for 240 hours, at 25° after approximately 168 hours, at 12.5° after 24 to 44 hours, at 0° after 8 to 16 hours, at −10° after 2 to 3 hours. The tests involving eggs are summarized in table 8.

TABLE 7.—*Hatching of louse eggs exposed for various periods at different temperatures to 20-cc. dosages of methyl bromide in individual fumigation bags, each containing approximately 25 pounds of clothing*

Temperature	Exposure	Total samples	Total eggs exposed	Eggs hatched	Fumigation tests	
					Total	Completely effective
° F.	*Hours*	*Number*	*Number*	*Number*	*Number*	*Number*
0	1	5	1,438	69	2	1
	1½	3	871	0	1	1
	2	25	4,275	34	9	7
	2¼	14	4,352	47	7	5
	2½	9	2,513	0	5	5
	2¾	6	1,284	0	3	3
	3	5	717	0	2	2
	4	4	998	0	1	1
10	¾	2	367	7	1	0
	1	4	790	0	2	2
	1½	5	1,096	0	3	3
	2	21	3,022	0	8	8
	2½	8	1,390	0	3	3
	3	3	351	0	1	1
12½	3	2	385	0	1	1
	4	2	300	0	1	1
25	½	4	646	1	1	0
	1	4	819	8	1	0
	1½	26	5,339	89	10	7
	1¾	[1] 17	2,666	18	8	5
	2	4	944	0	1	1
	2½	3	432	0	1	1
32	1½	4	1,218	0	2	2
36	½	2	651	4	1	0
	¾	2	774	134	1	0
	1	17	2,853	127	6	5
	1½	13	1,883	0	4	4
	1¾	[1] 6	972	14	4	1
	2	3	350	0	1	1
41	½	16	1,408	3	4	2
	⅝	12	830	0	2	2
	¾	11	674	0	2	2
	1	8	1,360	0	4	4
	1¼	8	956	0	4	4
46	¾	2	409	0	1	1
48	½	2	381	0	1	1
50–55	½	6	588	0	4	4
	¾	[2] 25	4,296	0	14	14
60–64	½	3	283	0	3	3
	¾	[2] 10	1,544	0	5	5
65–70	*Minutes*					
	20	11	692	38	2	1
	22	11	729	26	2	1
	24	11	783	10	2	1
	30	44	8,410	0	19	19
	45	8	1,190	0	4	4
70–75	*Hours*					
	½	19	2,771	0	12	12
	¾	8	624	0	4	4

[1] 2 samples consisted of eggs collected from clothing.
[2] 1 sample consisted of eggs collected from clothing.

Active lice were also exposed to low temperatures in some of the tests. Since facilities for feeding the lice were not available, the effectiveness of the exposure was determined by comparing the rapidity of death with that of lice held during the same period at room temperature. They apparently succumbed to shorter exposures than were needed to kill eggs. Minimum exposures for complete mortality appeared to be about 4 to 8 hours at 10°, 1 to 1½ hours at 0°, and 20 to 50 minutes at –10°.

TABLE 8.—*Hatching of louse eggs after exposure to temperatures between −15° and 42° F.*

Temperature	Exposure	Total samples	Samples with no hatching	Total eggs exposed	Eggs hatched	Control eggs	
						Total	Hatched
° *F.*	*Hours*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
−11 to −15	3	3	3	408	0	354	198
	4	3	3	387	0		
	5	3	3	394	0		
−10	½	2	0	670	186	962	831
	1	1	0	496	44	669	559
	1½	12	10	1,603	102	1,871	1,105
	2	13	11	1,792	38	2,085	1,234
	2½	12	11	1,203	2	1,416	674
	3	11	11	1,338	0	919	228
−9	¼	2	2	740	0	752	38
	1	2	2	702	0		
	1¼	2	2	543	0		
	2	2	2	676	0		
−8	⅓	1	0	259	41	369	317
−7	1/6	1	0	700	75	448	360
	⅓	1	0	584	124		
	½	1	0	525	152		
	⅔	1	0	623	59		
−6 to −10	43 min.	1	0	268	71	332	266
0	1	3	1	1,422	34	846	342
	1¼	2	0	703	450	680	639
	1½	2	0	365	129	177	130
	2	11	0	3,166	301	1,477	532
	2½	2	0	218	69	246	161
	3	4	0	805	87	846	342
	4	7	1	768	42	1,207	451
	5	4	0	404	47	172	103
	6	11	3	1,100	45	1,149	513
	6½	1	1	661	0	265	54
	7	4	0	339	14	277	189
	8	11	6	1,347	10	1,149	513
	16	6	6	697	0	358	235
	18	2	1	332	20	246	161
5	2	8	7	973	15	866	185
	4	12	10	1,242	9		
	6	8	7	1,528	2		
	8	8	8	1,279	0		
10	5	1	0	198	100	86	80
	6	1	0	216	[1] 7		
	17	1	0	135	39		
	20	1	0	136	18		
	25	2	1	305	6		
	48	1	1	57	0		
12½	2	2	0	157	68	177	130
	3½	2	0	213	38		
	8	6	0	605	185	449	231
	16	7	3	995	42		
	24	6	2	907	9	589	310
	44	2	2	305	0	177	130
	48	2	2	216	0	140	79
25	24	2	0	195	157	235	204
	48	1	0	104	78		
	120	3	1	678	62	570	331
	168	1	0	596	2	335	127
	240	2	2	262	0	235	204
36	120	1	0	606	88	335	127
	168	1	0	475	17		
	240	2	2	188	0	235	204
42	120	3	0	262	105	235	204

[1] No control sample.

DISCUSSION

The military forces decided that the high dosage-short exposure combination would best fit their needs. They adopted as standards an ampoule containing 20 cc. of methyl bromide, a bag 25 inches wide and made of material coated with either ethyl cellulose or Neoprene, the fold-over-tie closure, and the special pocket for the ampoule near the top of the bag. Directions for use stipulated that the bag should be laid on its side during exposure.

These decisions were based on the following facts: (1) 20-cc. ampoules would cost little more than 1 or 2-cc. ampoules because labor, not the cost of the contents, would be the determining factor, and bags could be reused with greater frequency with the shorter exposure period; (2) in bags 25 inches wide more economical use of fabrics was made, owing to certain stock widths; (3) the fold-over-tie closure had no detachable parts to be lost; (4) the pocket for the ampoule provided not only that the ampoule would always be located near the top of the bag but also that its position could be easily located from the outside of the bag; (5) fumigation would be successful, even though the bag remained upright, because of the fixed position of the ampoule near the top, should the directions for placing the bag on its side be disregarded.

The following exposure periods for the 20-cc. ampoules were recommended to the Office of the Surgeon General on the basis of partial results:

° *F.*	*Hours*
55 and above	¾
45 to 54	1¼
35 to 44	1¾
− 9 to 34	2¼
−10 and below	2¼, to cold alone

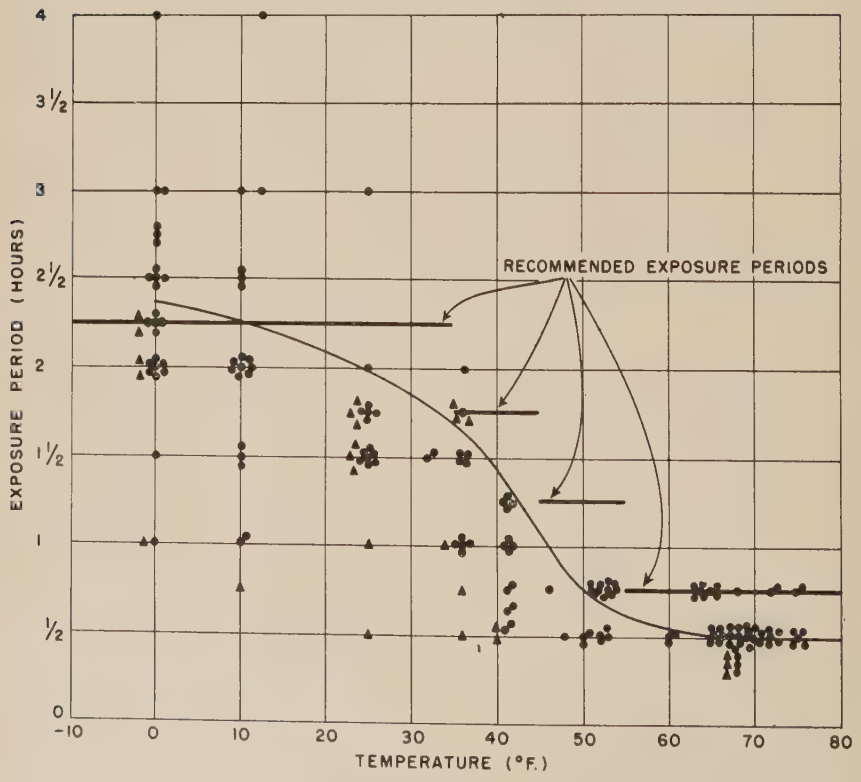

FIGURE 11.—Relation of recommended dosage schedules to the experimental data in table 7. The triangles represent tests giving incomplete mortality; and the circles, tests giving complete mortality.

Later tests, as given completely in table 7, in general supported these recommendations.

The relation of these recommendations to the results of tests are shown graphically in figure 11.

Pit Fumigation

Fumigation of louse-infested clothing in ground pits had been suggested as an emergency alternative to vault or individual-bag fumigation. A number of tests were made to determine the feasibility of this method, using dosages similar to those employed in the other methods.

Four types of pits were tested, as follows (fig. 12): (1) An individual pit, holding 1 barracks bag; (2) a trench pit, holding

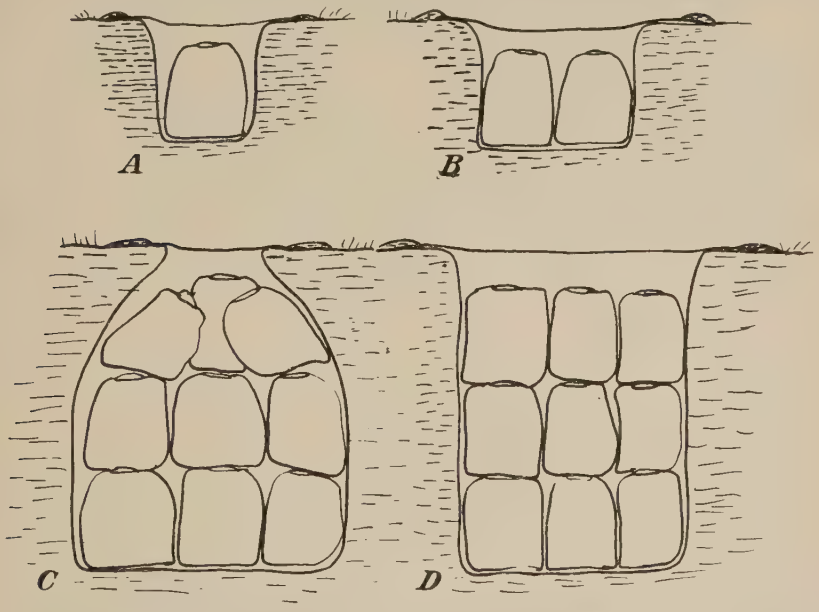

Figure 12.—Four types of ground pits used in fumigation tests: *A*, Individual pit; *B*, trench pit; *C*, jug-shaped pit; and *D*, straight-walled pit.

2 barracks bags side by side; (3) a jug-shaped pit, holding 4 to 21 bags; and (4) a straight-walled pit, holding from 20 to 30 bags. The method used in all tests was to dig a pit of the desired size, place the barracks bags in it, cover the opening, and introduce the methyl bromide from ampoules or 1-pound cans. At the end of the exposure period the cover was removed and the bags were immediately lifted from the pit for aeration. They were lifted out of the deeper pits by means of a hook on the end of a short pole.

The ampoules were broken by crushing the tip end with a pair of pliers held at arms length beneath the cover. The broken ampoules were dropped on the top of the barracks bags, the arm was quickly withdrawn, and the cover was sealed at the point of withdrawal.

One-pound cans were opened with the same dispenser as was used with the demountable vaults, and the fumigant was emptied into the pit through a short piece of tubing (fig. 13).

FIGURE 13.—Dispensing methyl bromide from a 1-pound can into a ground pit.

Several types of materials—including duck coated with ethyl cellulose, waterproof-canvas tarpaulin, wrapping paper, newspaper, a lightweight Army raincoat, and boards—were used to cover the openings of the pits. In each instance the cover was sealed by placing a ridge of soil around the margin (fig. 14).

The pits were all dug at the Agricultural Research Center, Beltsville, Md., where the soil is a sandy clay with some gravel, and the tests were made under varied conditions of weather and temperature.

All samples of louse eggs were from the Orlando colony. The samples were placed both within and outside the barracks bags, with most of them concentrated in the upper part of the pit because the gas concentration would naturally be less in that stratum. Samples were placed in the center of barracks bags, as well as at locations outside the bags. Fifty tests were made, involving 290 samples with a total of 63,145 eggs. Almost 20,000 additional eggs were observed in control samples.

The results, which are given in tables 9–12, show that ground pits are suitable for use in lieu of fumigation chambers or bags, at dosages comparable to those used in these devices. On calm days high mortality was obtained in small-mouthed pits without a cover, but when wind movement occurred it was necessary to provide a tight cover in order to obtain complete mortality. Of the covers used, canvas tarpaulins and boards were the poorest, whereas an army raincoat and duck coated with ethyl cellulose were the best. The size of the opening was also a critical factor, as a few eggs survived in all tests in the

straight-walled pit, which had a large opening. The small openings had the added advantage of being easier to cover (compare figs. 14 and 15).

FIGURE 14.—Sealing the edges of a cover on a ground pit.

FIGURE 15.—Covering the large opening of a straight-walled pit with supporting strips across the gap.

Dosages of 1 ampoule per bag where 1 or 2 bags were involved, 3 ampoules for 4 bags, 4 ampoules for 5 bags, and 8 ampoules for 10 bags were satisfactory. For lots of 12 to 21 bags (table 11) a 1-pound can (262 cc.) was sufficient. For lots of 20 to 30 bags in a straight-walled pit (table 12) one 1-pound can did not produce complete mortality, but this was considered to be due more to the character of the pit than to the dosage.

TABLE 9.—*Hatching of louse eggs after exposure to one 20-cc. ampoule of methyl bromide in individual ground pits, with one bag of clothing per pit*

Type of cover	Temperature	Exposure	Total samples	Total eggs exposed	Eggs hatched	Fumigation tests	
						Total	Completely effective
	° F.	Hours	Number	Number	Number	Number	Number
Ethyl cellulose duck	5	2	5	2,005	158	1	0
	14	2	5	2,029	0	1	1
	37	1½	4	1,646	0	1	1
	46–50	1	10	5,016	0	3	3
	60–66	¾	23	7,923	1	7	6
	70	1	4	1,238	0	1	1
Canvas tarpaulin	5	2	5	2,038	317	1	0
	14	2	5	1,680	118	1	0
	37	1½	4	1,505	0	1	1
	46	1	4	800	120	1	0

TABLE 10.—*Hatching of louse eggs after exposure to two 20-cc. ampoules of methyl bromide in trench pits, with two bags of clothing per pit*

Type of cover	Temperature	Exposure	Total samples	Total eggs exposed	Eggs hatched
	° F.	Hours	Number	Number	Number
Ethyl cellulose duck [1]	62	¼	4	484	0
Army raincoat	34	3	4	1,379	0
	38	1½	4	400	0
	55	1	4	1,233	0
	55	¾	4	870	0
Canvas tarpaulin	36	3	4	943	90
	40	2	4	1,213	0
	46	¾	2	647	1
Wrapping paper	30	2	4	894	0
	46	¾	2	563	0
Newspaper	40	1	4	1,812	0
	42	1½	4	1,372	0

[1] Only one 20-cc. ampoule was used.

AIRING OF CLOTHING

In the preliminary tests it was soon demonstrated that methyl bromide fumes in clothing could be easily reduced to a nonhazardous amount. Clothing removed directly from individual fumigation bags showed a high concentration of methyl bromide trapped between the folds of garments, when such were tested with a halide leak detector,[7] but these pockets were instantly dissipated by shaking the garment. Additional fumes were still absorbed in the clothing, which could be trapped in measurable amounts if the garments were folded again,

[7] A halide leak detector is a convenient instrument for making gross determinations of concentrations of methyl bromide between 50 and 1,000 p.p.m. It is used in the refrigeration industry to detect leaks in refrigerant lines. It operates on a principle of passing fumes of any halide over red-hot copper. If methyl bromide is present, color changes progressing from faint green to dark purple result, and can be used as gross indicators of the concentration.

TABLE 11.—*Hatching of louse eggs after ¾-hour exposure to various dosages of methyl bromide in jug-shaped pits*

Type of cover	Bags per pit	Temperature	Dosage	Total samples	Total eggs exposed	Eggs hatched
	Number	*° F.*	*Cc.*	*Number*	*Number*	*Number*
Wrapping paper	4	48	[1] 60	8	2,576	0
	4	64	[2] 60	8	1,900	21
	4	68	60	8	908	1
	4	68	[2] 60	8	1,144	79
None	5	49	[2] 100	5	500	105
	5	59	80	6	600	9
	5	60	80	6	600	80
	5	77	80	8	800	19
Boards	5	49	80	5	500	100
	5	67	80	7	700	14
Army raincoat	10	49	160	10	1,000	0
	12	45	262	8	800	0
	14	48	262	10	1,000	0
	15	55	262	10	1,000	0
	21	48	262	14	1,400	1

[1] Exposure period 1 hour.
[2] Exposure period ½ hour.

TABLE 12.—*Hatching of louse eggs after ¾-hour exposure to a 1-pound dosage of methyl bromide in straight-walled pits*

Type of cover	Bags per pit	Temperature	Total samples	Total eggs exposed	Eggs hatched
	Number	*° F.*	*Number*	*Number*	*Number*
Ethyl cellulose duck and blanket	20	55	10	2,028	13
Canvas tarpaulin	20	57	10	1,547	44
Ethyl cellulose duck	27	60	12	2,088	12
Ethyl cellulose duck and canvas tarpaulin	30	60	12	1,784	3
Wrapping paper	30	60	12	2,580	15

but if garments were donned, or blankets spread out, the rate of dissipation was such that dilution with air was enough to remove practically all hazard from inhalation.

Further testing demonstrated that if the barracks bags, upon removal from the vault, were placed in a well-ventilated location they would lose practically all fumes within an hour or two, without the necessity of spreading out the contents of the bags.

Thorough tests by the National Institute of Health[8] failed to produce irritation to skin when garments were donned immediately upon removal from fumigation vaults or bags, even when worn in the field by sweating men.

The accumulation of fumes from large quantities of fumigated clothing in closed buildings necessitated special ventilation provisions, which are discussed under Military Utilization of Methyl Bromide.

MILITARY UTILIZATION OF METHYL BROMIDE

The use of methyl bromide fumigation for delousing clothing by the military forces was divided into two general categories—field use, and permanent delousing stations at ports of debarkation.

[8] Unpublished report.

Field Use

The armed forces had a very comprehensive program for the suppression of typhus. The program included vaccination of all military personnel to induce immunity, the use of insecticidal powders for personal disinfestation, and fumigation for mass delousing to suppress epidemics. As affairs actually developed, the first two methods prevented any outbreak of typhus among American forces, so that little demand existed for mass delousing in the field. One bad outbreak in the civilian population at Naples was quickly suppressed by wholesale application of insecticidal powders, and marked the advance of this method.

Methyl bromide fumigation, however, was the most potent weapon at hand for mass delousing in the field during the early part of American participation in World War II, until the wholesale application of insecticidal powders demonstrated the potentialities of that method. The Office of the Quartermaster General developed two types of fumigation equipment for field use, based on the original models used in the experimental studies. They were (1) individual bags and ampoules, and (2) demountable vaults.

Figure 16.—Methyl bromide ampoule produced for military use: *A*, Individual paper container; *B*, protective cloth bag; and *C*, glass ampoule.

INDIVIDUAL FUMIGATION BAGS

Because of its simplicity and because it could be used by the individual soldier, the fumigation bag (fig. 9) was rushed into production in time to accompany the troops that invaded North Africa in the fall of 1942. The first bags were made of sateen coated with ethyl cellulose (No. (2), page 21), and used the fold-over-tie closure. The ethyl cellulose coating was found to have certain drawbacks, one of which was fusion during shipping, and at the same time it became a critical material because of its use for other purposes. This led to the development of a double fabric coated with Neoprene (No. (3), page 21), which was much better for the purpose. Further production was with this material. Other materials listed in table 6 were tested at various times in anticipation of a shortage of Neoprene, but such a substitution apparently never became necessary. This bag is a standard Quartermaster item (Bags, delousing, QM 27 B 208).

The glass ampoules of methyl bromide for use in the fumigation bag contained 20 cc. of the fumigant. Each ampoule was placed in a protective cloth bag, and packed in individual paper containers (fig. 16). The first production of ampoules was attended by many difficulties, but these were later overcome, and many millions of ampoules were eventually manufactured. These ampoules were also stocked as a Quartermaster item (Methyl bromide ampoules, QM 51 M 888). The Navy and the Marine Corps also draw this item from the Army Quartermaster depots.

DEMOUNTABLE FUMIGATION VAULTS

The 250-cubic-foot experimental vault (fig. 2) was turned over to the Quartermaster Corps as a model. From this a series of vaults

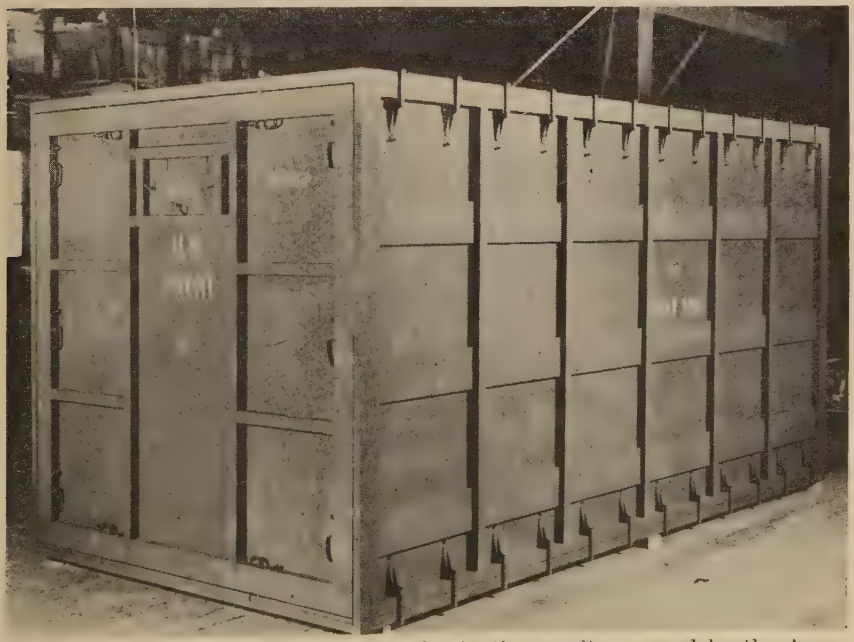

FIGURE 17.—One type of demountable fumigation vault procured by the Army.

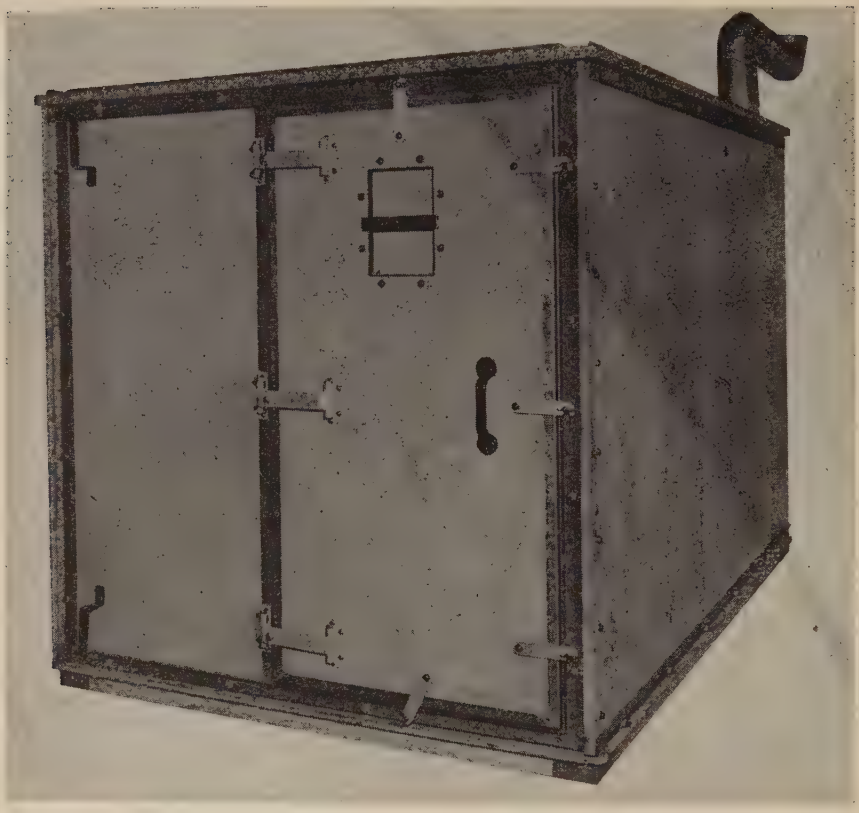

FIGURE 18.—Latest type of demountable fumigation vault procured by the Army.

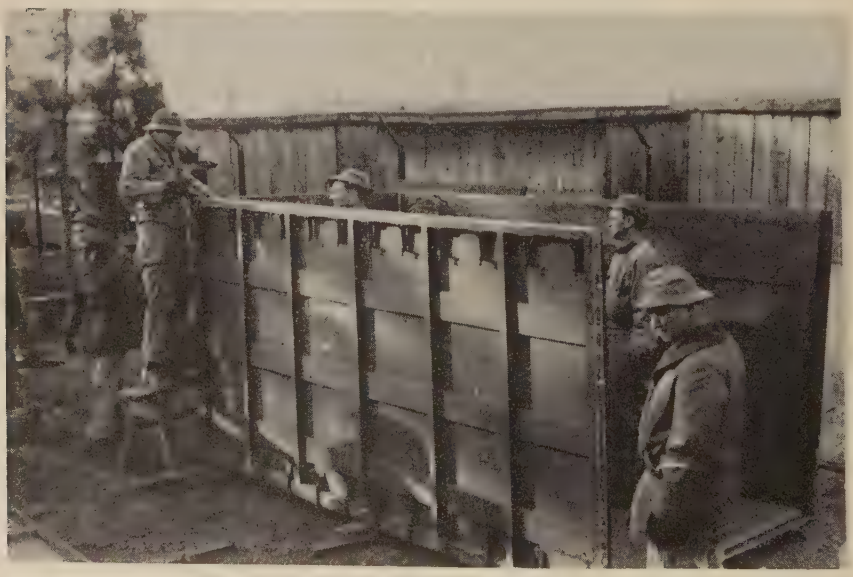

FIGURE 19.—The application of calking compound to the joining surfaces of panels in the erection of a demountable fumigation vault.

were designed and procured, all of which had a capacity of approximately 330 cubic feet and were composed of six panels each—top, bottom, sides, and ends. Each design (fig. 17) embodied the princi-

FIGURE 20.—An all-metal demountable fumigation vault used by the Marine Corps.

ples of the original model, except that in the last model an end panel containing a door was used, instead of the whole end panel being used as a door (fig. 18). The use of calking compound (fig. 19) to seal all joints between panels was found to make the vaults gastight with the minimum amount of labor.

These vaults were used by Mobile Fumigation and Bath companies, a number of which were activated as Quartermaster units. A company was composed of 2 platoons, each equipped for independent duty with a battery of 3 demountable vaults, showers, and canvas walks and shelters, and capable of handling from 150 to 300 men per hour. The platoon was set up for operation beside a source of fresh water in a manner to prevent the mixing of infested with deloused men. The men entered a disrobing station, where they removed their packs and clothing and placed them in numbered bags. While the men progressed through showers (heated by an oil-burning portable boiler) and were sprayed on all hairy parts with an ovicidal spray,

their clothing and equipment were being fumigated. By the time they reached the end of the line, their clothing was ready for them. By the use of 3 vaults loaded in rotation, a continuous operation could be maintained.

FIGURE 21.—A battery of fumigation vaults in operation at a permanent delousing station at a port in this country. The two vaults in the background are being unloaded, the two center ones are being ventilated prior to unloading and the two in the foreground are under fumigation. (Photo by U. S. Signal Corps.)

A number of demountable vaults of the type shown in figure 18 were procured by the Navy for permanent installation where needed at bases or hospitals. A similar type (fig. 20), but made of steel instead of plywood panels, was procured by the Marine Corps for use by Fumigation and Bath companies modeled after those activated in the Army.

PERMANENT DELOUSING STATIONS

Fumigation of clothing, plus the application of an insecticidal spray to the body, has been selected as the most satisfactory method of delousing prisoners of war and personnel reentering the United States from combat zones, to prevent the introduction of typhus-infected lice. This selection was based on the fact that the effect of a fumigation treatment is complete when clothing is returned to a prisoner or soldier at a delousing plant at a port of debarkation, whereas the complete effect of an insecticidal powder can be prevented

by its removal, once a louse-infested person is permitted to leave a delousing station.

Permanent delousing stations, with hourly capacity ratings ranging from 150 to 600 men, were built at all 10 of the ports of embarkation and debarkation in North America under Army supervision. These stations were designed by the staff of the Chief of Engineers. Permanent fumigation vaults, of a design similar to that of the experimental demountable vault, were built in batteries at each station (fig. 21). The walls are of concrete or sheet steel with doors of steel, or of wood lined with sheet metal. Several types are illustrated in figures 22–25. At one port an available vacuum-fumigation plant was expanded and utilized which permitted the use of a shorter exposure period. Hundreds of thousands of prisoners of war and Army personnel have been treated at these delousing stations.

Each delousing station is laid out so as to prevent recontamination (fig. 26). The personnel to be deloused enter at one point and proceed through various steps, until they leave, without having had contact with persons entering behind them.

Disposal of the fumigant after the fumigation was completed was a more difficult problem in permanent stations than in mobile field units, owing to the accumulation of fumes from clothing brought into dressing rooms. Special shake-out rooms, with forced ventilation to remove the fumes constantly, were installed. All delousing stations now have provisions for keeping the concentration of methyl bromide in the air below 30 p.p.m. at all times.

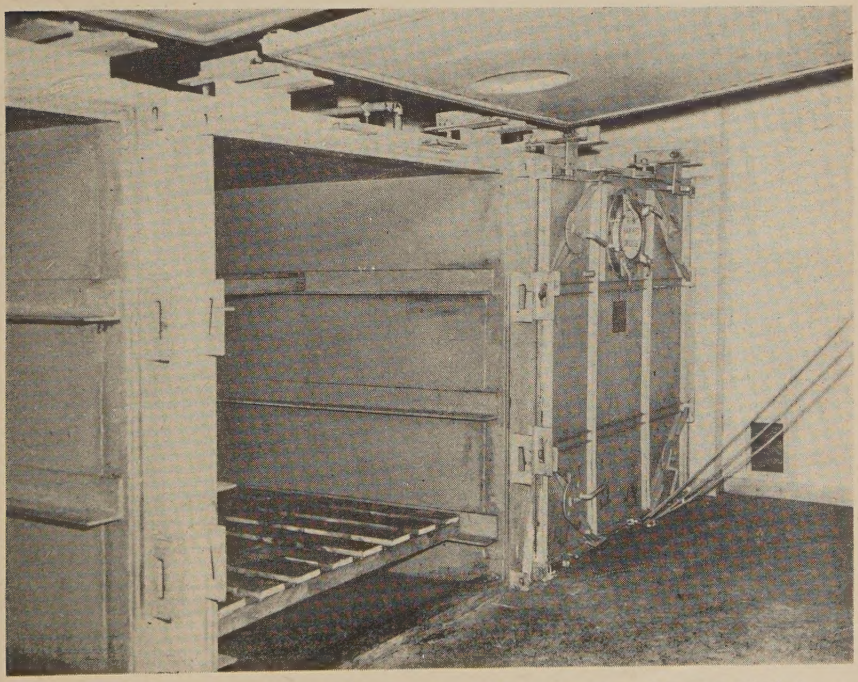

FIGURE 22.—Permanent fumigation vaults, with concrete walls and steel doors, at a delousing station. (Photo by U. S. Signal Corps.)

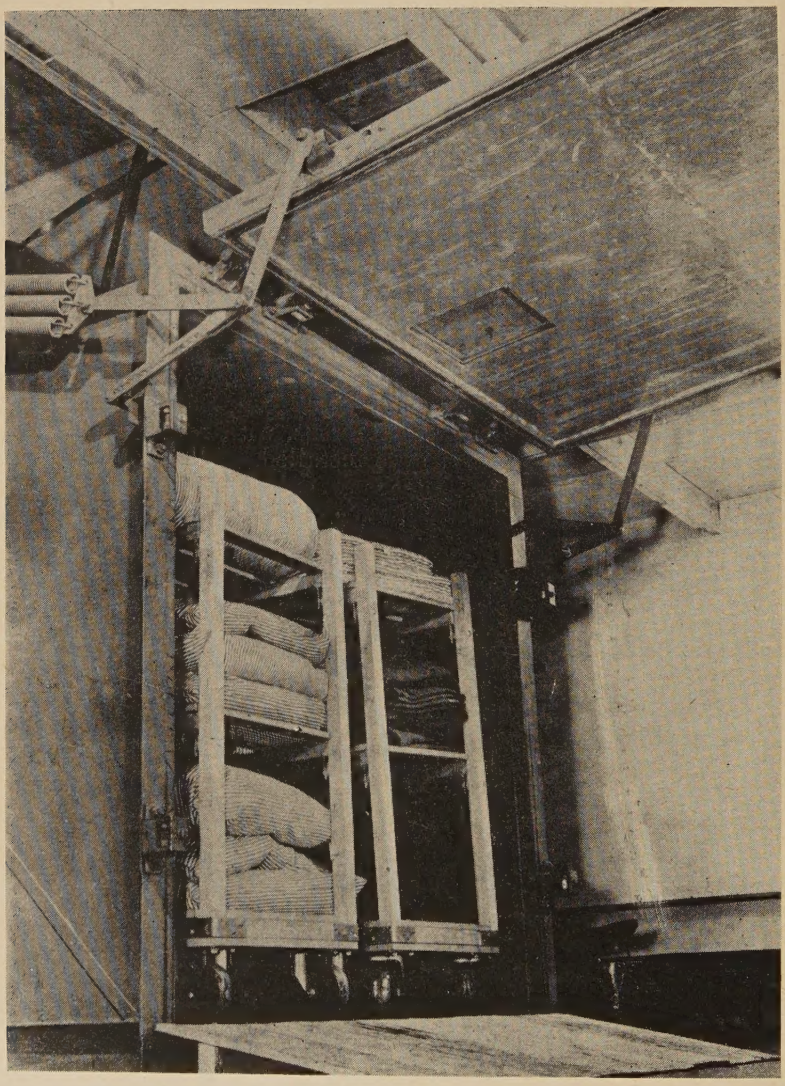

FIGURE 23.—An all-steel vault built for installation at a delousing plant.

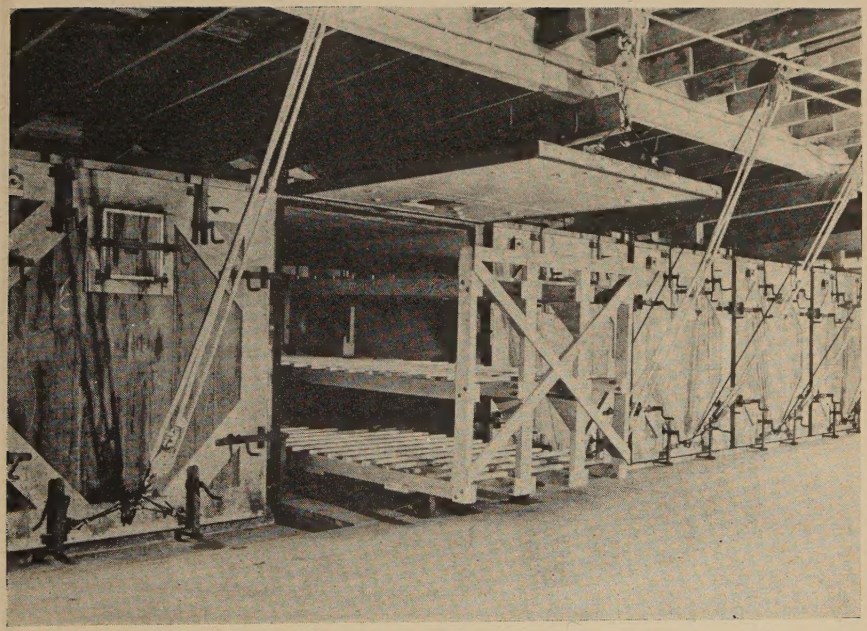

FIGURE 24.—Concrete fumigation vaults with wood and sheet-metal doors. (Photo by U. S. Signal Corps.)

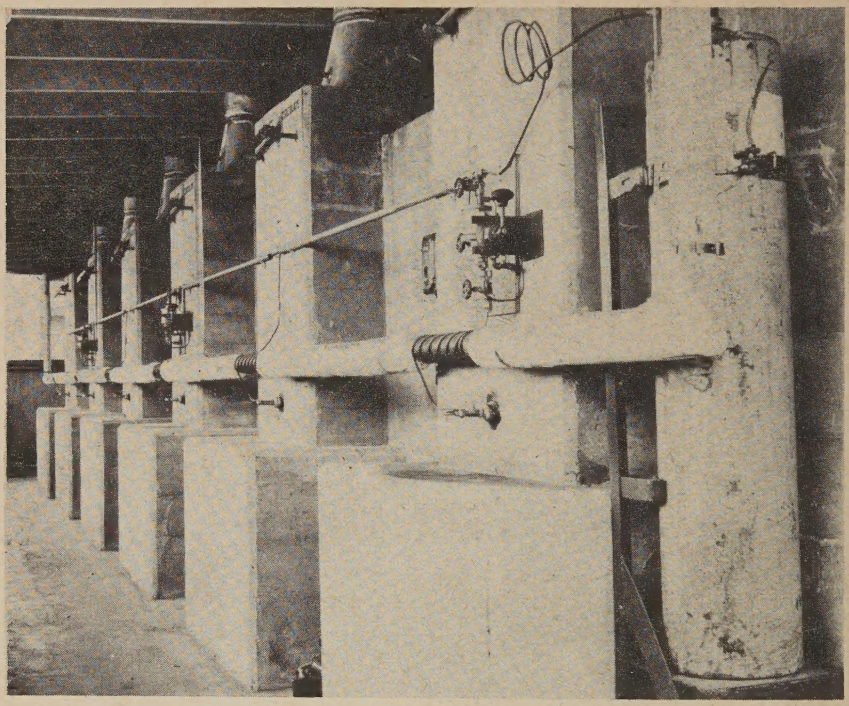

FIGURE 25.—Rear view of the battery of six concrete fumigation vaults shown in figure 25. The blower, circulation duct, and exhaust vent are in a recess in the rear wall of each chamber, the outside of which is shown here. Each dispenser serves two chambers, and the methyl bromide is supplied from the large pressure cylinder at the right. The volatilizer in each instance is a copper tube coiled around a steam pipe. (Photo by U. S. Signal Corps.)

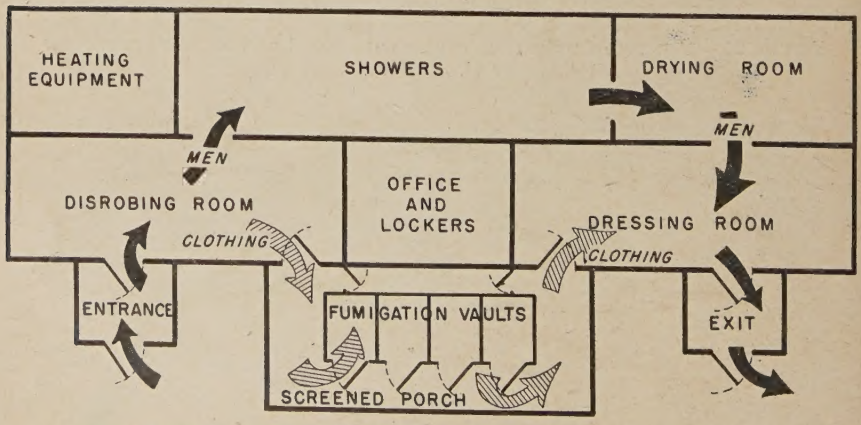

FIGURE 26.—Typical floor plan of a permanent delousing station.

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